

REFINING COAL LIQUIDS: WHERE WE STAND

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ABSTRACT

In extensive studies sponsored by the US Department of Energy, syncrudes from a variety of coals (bituminous, sub-bituminous, lignite) and several direct coal-liquefaction processes (SRC-II, H-Coal, EDS, ITSL) were catalytically hydroprocessed in pilot plant tests. The results show that these syncrudes can be refined to transportation fuels (diesel, jet fuel, gasoline) using commercial petroleum hydroprocessing technology. Key factors that determine how easy or difficult a particular syncrude is to refine are boiling range (endpoint), hydrogen content, and heteroatom content. This paper reviews experimental results, discusses alternative refining routes, compares projected costs for these routes with different feeds, and identifies areas in which further research is needed.

INTRODUCTION

The name "syncrude" or "synthetic crude" is used rather loosely to describe hydrocarbon oils derived from sources other than petroleum. The name implies that they can serve as substitutes for petroleum crude. However, liquids produced from coal in direct-liquefaction processes are quite different from petroleum. Can they really take the place of petroleum? Can we make products from coal syncrudes that meet petroleum specifications using conventional refining technology? If so, are there differences between products from petroleum and those from coal-derived oils? Are fuels from coal better or worse than conventional petroleum-derived fuels? How much will it cost to refine coal syncrudes?

For several years, Chevron under a contract with the US Department of Energy has been studying the refining of coal liquids. Detailed results are given in a series of DOE Interim Reports (1). This paper briefly reviews that work. Also, we will address the above questions, and identify areas in which further research is needed. For a more extensive overview of the state-of-the-art in coal liquids upgrading, the reader is referred to a recent comprehensive study by Oak Ridge National Laboratory (2).

DOE supplied to us the "net whole-liquid process product" from each of a group of liquefaction processes for which they have supported research and development. The processes are Solvent-Refined Coal (SRC-II), H-Coal, Exxon Donor Solvent (EDS), and Integrated Two-Stage Liquefaction (ITSL).

In our program, we developed conceptual refining schemes for processing each of the syncrudes in a "grass-roots" refinery (that is, a completely new stand-alone refinery) to produce fuels meeting current specifications. Then, we conducted pilot plant tests for the key upgrading steps to make reasonable estimates of commercial catalyst performance. Finally, detailed engineering studies were made to determine stock balances and estimate refining costs.

PROPERTIES OF COAL-DERIVED OILS

Table I summarizes some of the key properties of the coal-derived oils that served as feedstocks for our upgrading studies. For comparison, Arabian Light crude is also included. Each of the coal oils was selected by DOE to represent, as nearly as possible, the net whole-liquid product from the liquefaction process at the time it was chosen. However, it should be recognized that the properties may not be representative of the oil that an optimized commercial process would produce. All of the processes have only operated on a pilot plant scale; and none is yet fully optimized. Furthermore, each process can operate in various modes, generating products with different properties.

These oils differ from typical petroleum crudes in a number of ways: (1) They are generally much lower boiling than typical petroleum crude. (2) They contain no residuum. (3) They contain mostly condensed cyclic compounds and few paraffins. (4) Most have relatively high heteroatom contents, particularly nitrogen and oxygen. (5) Most have a relatively low hydrogen content compared to petroleum.

Figure 1 shows typical distillation curves of several coal-derived oils compared to typical Middle-East petroleum crudes. (The curves for the H-Coal oils are not shown in the figure, but fall into the envelope included by the other coal oils.) The coal oils contain little high boiling material compared to petroleum because most of the higher boiling oil is typically used as a recycle solvent in the liquefaction process and ultimately converted to lower boiling products. The boiling range of the oil used as solvent can vary, however, depending on how the liquefaction process is operated. Therefore, boiling range of the net product can also vary, and upgrading studies can help guide the selection of the best operating mode for the liquefaction facility.

There are some significant differences among the different coal liquids; particularly between the two-stage liquefaction product, ITSL oil, and the others. The ITSL oil contains a much larger middle distillate fraction (76 LV% boils between 400°F and 700°F) and less naphtha. It is also lower in heteroatom content and (except for SRC-II) lower in hydrogen content.

Some of the as-received oils, in particular the EDS and H-Coal oils shown in Table I, have appreciable quantities of a high endpoint "tail", which makes these stocks relatively hard to hydrotreat. We distilled these oils to remove the highest boiling fraction and hydrotreated the distillates as well as the whole oils. Properties of the re-distilled oils are also given in Table I.

In addition to the oils shown in Table I, we also studied the upgrading of several higher boiling coal oils. Results are given in DOE reports (1) and a recent paper (3). The heavy fractions of these oils could either be used as recycle solvent or be part of the net liquid product, depending on how the liquefaction process is operated.

CONCEPTUAL REFINING PLANS

We considered a variety of conceptual refining plans for orienting and guiding the pilot plant work. We will limit the discussion here to two basic plans and later use them as a framework for comparisons between the different coal-derived oils that were

processed. Simplified flow schemes for these refineries are shown in Figures 2 and 3. Each scheme represents the main hydrocarbon flow in a refining module, excluding the many supporting plants necessary in a full-scale "grass-roots" refinery, such as by-product recovery, waste treatment and hydrogen supply. Considering hydrocarbon flow alone, these coal liquid processing schemes are less complex than those required for a modern large petroleum refinery processing heavy crudes. This is because these coal liquids contain no residuum. But, whereas the flow scheme would be simpler than for petroleum, the processing would be at least as severe.

In the first refining plan (Figure 2), the target products are gasoline and middle distillates (diesel and/or jet fuel). Because most of the feed already boils in the range of the desired products, no cracking conversion process is required. The whole oil is hydrotreated at a high severity to produce specification jet fuel or diesel, and the naphtha is catalytically reformed to high octane gasoline. [This refinery could also produce No. 2 heating oil as the middle distillate product rather than jet/diesel. In that case, the hydrotreater could be operated at a lower severity than required for specification jet or diesel.]

In the second refining plan (Figure 3), as shown, the target product is all gasoline. In this case, as in the first refining scheme, the oil is first hydrotreated. However, the severity can be somewhat lower than in the first case, because the purpose is to remove heteroatoms rather than to make finished products. Then, the hydrotreated oil is hydrocracked to convert the high boiling fraction into naphtha, and the naphtha is then catalytically reformed to gasoline.

HYDROTREATING RUNS

As indicated earlier, full-boiling-range coal oils require relatively high hydrotreating severities to remove the heteroatoms and increase the hydrogen contents. Our hydrotreating studies have been described in detail elsewhere (1). Table II briefly compares results obtained with the feeds listed in Table I at comparable conditions with a single commercial hydrotreating catalyst, Chevron's ICR 106. The tests were made at 750°F average catalyst temperature, two hydrogen partial pressures (2300 and 1800 psia), and three different liquid hourly space velocities (LHSV): 0.5, 1.0, and 1.5 volumes of feed per volume of catalyst per hour.

The best direct comparison is at 1.5 LHSV and 2300 psia because all the feeds were tested at these conditions and the results show major differences. In Table II, the feeds are listed in order of ease of hydrotreating. The easiest feeds to upgrade are the redistilled Illinois H-Coal and lignite EDS, as indicated by the low product nitrogen and aromatic contents. Of the full-boiling-range oils, the Wyodak H-Coal is easiest, probably because of its high hydrogen content and low average boiling range.

ICR 106 catalyst was quite stable at 2300 psia for hydroprocessing all the feeds, except for the full-boiling-range lignite EDS oil. With the EDS oil, there was measurable decrease in hydrogenation activity with time on stream, even at 0.5 LHSV. We believe that this result was due to coke-precursors in the high endpoint "tail" of the EDS oil (Figure 1). When the high boiling

fraction was removed by distillation, the catalyst was very stable at these conditions.

At a lower pressure (1800 psia) and 1.5 LHSV, the catalyst was stable for both redistilled oils, and two of the full-boiling-range oils: Wyodak H-Coal and Illinois ITSL. However, in addition to the EDS oil, the Illinois H-Coal and the SRC-II oils also caused measurable catalyst deactivation at these conditions.

The hydrogen consumption needed for a given product quality from these coal liquids depends on their hydrogen content and heteroatom contents. It is higher than that usually needed in petroleum hydrotreating. Still, in spite of the relatively severe hydro-processing conditions, there was little cracking to light gases, and liquid-volume yields were typically higher than those obtained when hydrotreating petroleum (because of the higher hydrogen input).

We compared a series of oils produced in the ITSL process from two different coals--Illinois and Wyodak. These oils have different endpoints, and are not all full-boiling-range oils. However, Figure 4 shows a fairly good correlation between the required catalyst temperature for 0.5 ppm nitrogen product and the feed endpoint, regardless of coal source. With the oils with endpoints of 750°F or below, the catalyst is very stable, and catalyst lives of several years can be predicted at the test conditions. The higher temperatures required for hydrotreating the higher boiling feeds would significantly shorten the catalyst lives.

HYDROCRACKING RUNS

In a recent paper (4), we discussed in detail the hydrocracking of a representative coal oil, hydrotreated ITSL oil. Hydrocracking is a flexible process that can be varied to make only naphtha (as shown in Figure 3) or a combination of gasoline and middle distillate if the recycle cut point is increased. The products from hydrocracking coal oils are similar to those obtained from hydrotreating; the quantities of each can be varied depending upon the demand.

PRODUCT PROPERTIES

General Comments. After hydrotreating, products of similar boiling ranges from the different liquefaction processes and different coals are actually quite similar. After removal of the heteroatom-containing compounds, the products consist mainly of cyclic hydrocarbons. The severity of hydrotreating determines the amount of hydrogenation of aromatics to naphthenes. There are, however, some differences. Products from sub-bituminous coals contain more paraffins than those from bituminous coals, but fewer paraffins than products from lignites. Even so, the paraffin contents of lignite products are lower than petroleum products. For a given coal, ITSL process products contain fewer paraffins than those from the other processes. (Probably less ring opening occurs because of the lower severities required in two-stage liquefaction.)

Naphtha. Hydrotreated and hydrocracked naphthas from coal liquids are excellent feeds for catalytic reformers because of the high content of cyclic compounds. The naphthenes can be converted to high octane aromatics by reforming at relatively mild conditions. Also, because they are easy to reform, such naphthas can be reformed

at higher severities to an extremely high octane product, which makes a superb gasoline blending stock or which could be used for the production of benzene, toluene, and xylene as chemicals. Because of the mild conditions required to produce a given octane product compared to petroleum, much of the hydrogen previously consumed can be recovered (5).

Jet Fuel. To make jet fuel from these coal liquids, most of the aromatics must be saturated. To meet the smoke point specification of 20 mm or higher, the aromatic content for a full boiling range kerosene would typically be no higher than about 10 LV%.

Jet fuels prepared from coal liquids offer some unique advantages over those prepared from petroleum. They have unusually low freezing points (because of the low paraffin content). Also, because they contain high concentrations of naphthenes, they are very dense and have high heating values by volume. Therefore, they could have specialized uses such as for military fuels.

Franck et al (6) compared different hydrocarbon types to determine which had properties best suited for jet fuel. They showed that naphthenic hydrocarbons with two or three rings (molecular weight between 120 and 200) were the only ones to have all the following properties simultaneously: (1) high volumetric heat of combustion, (2) satisfactory mass heat of combustion, (3) acceptable thermal stability, (4) very low freezing point, (5) acceptable low temperature viscosity, (6) low volatility, and (7) acceptable flame characteristics. Because coal liquids are extremely rich in these compounds, they make high quality jet fuels.

Diesel Fuel. Diesel products from coal-derived oils also meet typical specifications including cetane number. As with jet fuel, most of the aromatics have to be hydrogenated before the specification for cetane number of 40 is met. With all the oils studied except ITSL oil, the aromatics content has to be about 10 LV% to meet this specification. With ITSL oils, the specification could be met with about 20 LV % aromatics present. The ITSL diesel had a somewhat higher average boiling range than the other diesels oils, and this may account for the difference.

Coal-derived liquids respond well to certain cetane improvers. Because of the high cost of hydrogen, it may be cost effective to substitute cetane improvers for hydrotreating severity to some extent. For example, adding 0.3 LV% octyl nitrate (a commercial cetane improver) to diesel fuels from hydrotreated Wyodak H-Coal oil was shown to increase the cetane number by 6-8 numbers (7).

As with jet fuel, the diesel fuels also have excellent cold weather properties, and high volumetric energy contents.

Heating Fuel. Although the primary purpose of our studies is to make transportation fuels, we have also evaluated No. 2 heating oil as a possible product. Generally, it is possible to make heating oil by hydrotreating coal liquids less severely than is necessary to produce jet and diesel fuels. All specifications can be met, except gravity. Probably, the gravity specification could be waived in some applications. (Usually, the gravity specification also can be met by hydrotreating at higher severity to make diesel-quality product.)

DETAILED REFINING PLANS AND STOCK BALANCES

Based closely on the results of the pilot plant work and conceptual refining plans, we developed detailed refining plans and stock balances for each coal-derived feedstock. The primary basis for the detailed plans and stock balances was to produce 50,000 barrels per calendar day of the desired products in a complete new refinery. This refinery would include all necessary supporting facilities such as utility plants, tankage, and required environmental control equipment. The refinery would be self-sufficient in fuel and hydrogen plant feed. It would produce finished distillate fuels meeting current specifications along with environmentally acceptable by-products, e. g., sulfur and ammonia.

Stock balances have two kinds of results: (1) individual plant capacities and (2) feed and product flow rates. Interested readers will find detailed comparisons of the stock balance results in the Tenth Interim Report listed in reference 1; only a brief summary is presented here. We used the stock balance plant capacities as part of the basis for the refining cost estimates. Stock balance flow rates are summarized as product yields along with the costs.

REFINING YIELDS AND COST ESTIMATES

Table III summarizes these results for the coal-derived oils studied by mid-1985. The costs are all given on a common basis, first quarter 1984 dollars. (Costs studies of ITSL oil upgrading are incomplete at the time of writing.) The oils are of two general classes: the "net whole-liquid process product" as received from DOE, and the stock as re-distilled at Chevron Research. There are three general refining modes as discussed above: two-stage hydrocracking to produce only motor gasoline, severe hydrotreating to produce motor gasoline and kerosene jet fuel or diesel, and less severe hydro-treating to produce motor gasoline and heating oil.

Because we assume "grass-roots", self-sufficient refineries for the comparison, the net yields allow for using part of the coal-derived feeds and/or refined products for hydrogen production and refinery fuel.

The investment costs are estimated from correlations of costs of actual petroleum processing plants built by Chevron over the last twenty years, adjusted for the many factors which have changed or could change if and when a synfuels refinery is constructed. The synfuels-specific plants (the hydrotreaters and hydrocrackers) are estimated in further detail; design conditions are based directly on the pilot plant data.

The histories of large, first-of-their-kind engineering projects show that the refining cost estimates will almost certainly change as synfuels development moves closer to commercialization. Therefore, the main value of the present estimates is not for predicting ultimate synfuels costs, but rather for comparing one set of results versus another--different feeds, different processing schemes, and different product mixes. The results, then, can guide future research and development. For this reason, we made a strong effort to keep the estimates consistent with each other.

From these refining costs, we can reach some qualitative conclusions. For example, the feeds rank differently depending on the product slate. To make all gasoline from the as-received stocks, the cost ranking is Pitt Seam SRC-II > Lignite EDS > Illinois H-Coal > Wyodak H-Coal. But the EDS stock would be the most expensive from which to make a combination of gasoline and jet fuel or diesel. Also, re-distilling affects the refining cost of each feed differently: \$4/BBL reduction for Lignite EDS, \$2.5/BBL for Illinois H-Coal, and no reduction for Wyodak H-Coal.

The refining yield and cost differences can be rationalized by considering the boiling range and composition of each feed: (a) higher boiling stocks are more expensive to refine but lend themselves to higher boiling products; (b) heteroatom content can influence refining cost, although it usually trends with boiling range; and (c) the cost difference between refining to gasoline and refining to jet and/or diesel fuel increases as the hydrogen content of the feedstock decreases. (For example, with high hydrogen-content feeds such as Wyodak H-Coal oil, the costs of making all gasoline or a combination of gasoline and jet/diesel are about the same. But with low hydrogen content feeds such as SRC-II, it is appreciably less expensive to make all gasoline than the combination.)

RELATIONSHIPS BETWEEN COAL-LIQUID AND PETROLEUM UPGRADING COSTS

Several facts must be kept in mind if one is to judge what these costs mean and how they might be applied in situations other than internal comparisons. First, with the present and quite probably the future excess of petroleum refining capacity in this country, no new "grass-roots" refineries are likely to be constructed for coal-derived oils. Instead, refining facilities either will be integrated with liquefaction plants, or even more likely, coal-derived stocks will be refined along with petroleum in existing refineries. Of course, refining costs will then be entirely different from those presented here. Second, petroleum refining costs themselves increased 50 to 60 percent between 1980--when we first published estimated costs of refining coal-derived oils--and 1984, the basis for the costs presented here. (They are estimated to have increased an additional 15% by the first quarter of 1986.) Correction factors must be applied to earlier cost studies, whether for coal-derived oils or petroleum. Finally, the size of the refinery affects per-barrel cost. For example, product from a 50,000 barrel-per-day refinery costs about 20% more than that from a 100,000 barrel-per-day refinery. [(1), Report 10].

As with coal liquids, the costs of refining petroleum vary widely, depending on boiling range, heteroatoms and metals contents, and desired product slate. Most petroleum crudes have the advantage of being relatively hydrogen-rich, but the disadvantage that they contain varying amounts of residuum.

There is little question that distillate fuels from coal will be more expensive than those from petroleum, based on the current prices of petroleum and state-of-the-art liquefaction and refining technologies (8). This is largely the result of the high cost of liquefaction, rather than the upgrading costs. We have not attempted to compare the costs reported here with those for upgrading petroleum. However, other studies --in particular, those of Universal Oil Products, Inc. (UOP) (9, 10, 11)--serve to put these costs in perspective.

For example, Sikonia et al (9) compared the costs of refining an H-Coal product and two petroleum crudes on an internally consistent basis. Overall refining costs were about the same--within 5% of each other. However, product slates were different--the coal oil was refined to gasoline and diesel, the petroleum crudes to a wider variety of products. In order to rank the feedstocks, the authors assumed a set of product values. Then, from these values, they calculated how much each feedstock was worth to the refiner. They concluded that the coal oil was worth about \$2/BBL more than Mexican Maya heavy oil, but about \$2.50/BBL less than Arabian Light crude oil. (It will, of course, be recognized that product values will change with time. Therefore, the ranking could change.)

In another study (10), Gembicki et al calculated costs for a conventional refinery, a heavy-oil refinery, and a coal-liquid refinery producing both gasoline and No. 2 heating oil. For that product slate, refining costs were greatest for the heavy oil refinery and least for the coal liquids refinery. The authors explained that the heavy oil required the largest conversion facilities, as it contained the least amount of distillables compared with the other feedstocks. The coal-liquids refinery was the least expensive because of the small quantity of residual matter found in the coal liquid. Nevertheless, they concluded that the entire cost of upgrading coal to distillate fuels would be much more expensive than upgrading heavy crude because of the high cost of coal liquefaction.

In an earlier analyses for DOE (11), UOP concluded that a refiner could afford to pay more for coal liquid than a Light/Heavy Arabian crude oil blend and still realize the same rate of return on investment for a new refinery specific to the feedstock processed. (Again, this applied to a specific product slate, and product values were assumed.) In this study, the small proportion of coal liquid feedstock boiling higher than the product endpoint was significant. If the proportion of such residue increased, the relative value of coal liquid would decrease due to the higher processing cost to convert heavy oil to lighter products.

CONCLUSIONS: WHERE WE STAND

If the properties of the coal liquids shown in Table I are indeed representative of the liquefaction products made from an eventual commercial process, there is virtually no doubt that they can be upgraded to specification transportation fuels using modern commercial petroleum-processing technology. Of course, not every refinery could handle them. High-pressure hydrotreating units would be necessary.

Still, important questions remain as to how the liquefaction and refining of coal liquids will interface, and additional research is needed to optimize this relationship.

In most liquefaction processes, a substantial degree of product slate adjustment can be achieved within the liquefaction plant itself by changes in the process variables. The relationship between cost of these changes and the cost of downstream refining must be considered. The most economical combination may require product slate adjustment in the main process, followed by appropriate downstream units for product upgrading to market specifications (12). For example, MacArthur et al (13) evaluated the merits of operating the H-Coal process in the mode of extinction recycle of 650°F+ vacuum gas oil, compared to typical H-Coal operating conditions. They concluded that

this operating mode improved the selectivity to liquid product and reduced commercial plant investment (including upgrading) by 10%, and the cost of producing coal liquids by 6%, compared to typical operation.

In addition to boiling range, another factor that has a large effect on the cost of refining coal-liquids is their hydrogen content. Because the finished fuels require a certain hydrogen content, it either must be added during the liquefaction process or during refining. Downstream hydrotreating makes efficient use of hydrogen, because it produces very little by-product light gas. Therefore, it may be cost effective to have a relatively hydrogen-poor liquefaction product (as that from the ITSL process shown in Table I), even though this adds to the downstream cost. Also, cheaper sources of hydrogen would significantly reduce costs. Furthermore, if the liquefaction and refining facilities were integrated, they could share the same hydrogen plant and additional costs could be saved.

The difficulty and, therefore, the cost of hydrotreating a coal-derived liquid increases rapidly with its boiling range, particularly if the endpoint is increased above 700°F. This is because of the high concentration of condensed aromatic and polar compounds in the high-boiling fractions which tend to cause rapid deactivation of the catalyst by coke deposition. Therefore, if at all possible, the high boiling fraction should be removed from the 700°F-oil before hydrotreating. Usually, the higher boiling oil can be used to advantage as recycle solvent in the liquefaction process. Clearly, sharp separation between the net liquid product and the heavy oil to be recycled is desirable. None of the oils shown in Table I contain large amounts of 700°F+, but even the amounts present have a very large deleterious effect. When this material is removed by distillation, the oils become much easier to upgrade.

Coal liquids boiling in the 700-900°F range are relatively hard to upgrade. However, it is technically feasible to hydrotreat coal oils in this boiling range to acceptable products. Almost certainly, the cost will be high, and more research is needed to optimize their upgrading. Clearly, from the viewpoint of the refiner, it is desirable to have them consumed as recycle solvent in the liquefaction process. Also, most of the biologically hazardous material is reported to be in the 700°F+ oil (2), and environmental problems in refining can be minimized if these materials are recycled to extinction at the upstream facility.

Any coal oils boiling above 900°F would be exceedingly hard to upgrade using conventional petroleum technology. New technology would be required to handle these materials.

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4	FE-2315-50	Paraho Shale Oil	June 1980
5	DOE/ET/10532-T3	H-Coal	September 1981
6	DOE/ET/10532-T5	SRC-II	April 1982
7	DOE/ET/10532-T11	H-Coal, EDS	January 1983
8	DOE/ET/10532-T17	H-Coal	September 1983
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TABLE I

COAL - DERIVED PILOT PLANT FEEDS; COMPARISON OF PROPERTIES

Liquefaction Process	Whole Liquid (as Received)				* Redistilled			
	ITSL Illinois No. 6	H-Coal Illinois No. 6	H-Coal Wyodak	SRC-II Pitts- burgh Seam	EDS Texas Lignite	H-Coal Illinois No. 6	H-Coal Wyodak	EDS Texas Lignite
Type of Coal								ARABIAN LIGHT CRUDE
Inspections								
Gravity, deg API	17.6	25.8	35.1	18.6	29.0	28.1	35.1	33.4
Sulfur, ppm	700	2000	410	2900	1180	1400	250	1000
Nitrogen, ppm	730	4600	1700	8500	3000	3300	1500	1600
Oxygen, ppm	1800	18000	8500	37900	13200	19600	6700	23400
Hydrogen, Wt%	10.68	11.29	12.74	10.46	11.25	11.44	12.97	11.63
Carbon, Wt%	88.99	86.25	86.20	84.61	86.41	86.13	86.18	85.77
Hot Heptane Insolubles, ppm	290	3500	680	469	1300	54	< 10	264
Ramabottom Carbon, Wt%	0.30	0.29	0.23	0.70	0.57	0.30	0.15	0.18
TBP Distillation, deg F @ St/ 5	97/214	56/177	53/156	56/189	53/164	56/170	52/165	47/142
10/30	314/471	213/333	173/261	241/379	203/317	200/310	178/269	171/296
50	560	404	354	424	370	380	356	342
70/90	609/676	476/588	429/535	473/562	452/662	440/508	424/509	404/512
95/99 LV%	703/763	654/765	602/785	642/820	799/950	538/589	542/603	547/627
Boiling Range, LV%								
St - 400 deg F	18	49	60	37	57	57	63	69
400 - 700 deg F	76	48	38	60	35	43	37	30
700 deg F +	6	3	2	3	8	0	0	1
* Overhead, LV% of As-received Oil :								
						Illinois H-Coal	Wyodak H-Coal	EDS
						87	96	87

TABLE II

HYDROTREATING PILOT PLANT TESTS FOR COAL-DERIVED OILS

750 deg F Catalyst Temperature; Fresh ICR 106 Catalyst

Liquid Hourly Space Velocity	0.5	1.0	1.5	1.5
Hydrogen Pressure, p.s.i.a. (approximate)	2300	2300	2300	1800
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Re-distilled Illinois H-Coal				
Hydrogen consumption, SCF/BBL		2000	1950	
Product nitrogen, ppm		< 0.3	< 0.3	
Product aromatics, LV%		2	5	
Re-distilled Lignite EDS				
Hydrogen consumption, SCF/BBL			1600	1500
Product nitrogen, ppm			< 0.3	< 0.3
Product aromatics, LV%			6	10
Wyodak H-Coal				
Hydrogen consumption, SCF/BBL		1225	950	
Product nitrogen, ppm		< 0.3	< 0.3	
Product aromatics, LV%		3	13	
Illinois ITSL				
Hydrogen consumption, SCF/BBL	*	*	950	600
Product nitrogen, ppm			0.4	6
Product aromatics, LV%			38	58
Illinois H-Coal				
Hydrogen consumption, SCF/BBL	2150	1600	1275	825
Product nitrogen, ppm	< 0.3	0.3	10	50
Product aromatics, LV%	2	20	35	45
SRC - II				
Hydrogen consumption, SCF/BBL	3100	2500	2000	1725
Product nitrogen, ppm	< 0.3	0.4	20	150
Product aromatics, LV%	4	20	40	47
Lignite EDS				
Hydrogen consumption, SCF/BBL	1550		825	725
Product nitrogen, ppm	< 0.3		170	350
Product aromatics, LV%	16		38	40

*

The Illinois ITSL was tested at lower temperature.
The results:

L H S V	0.5	1.0
Temperature, deg F	710	730
H ₂ Consumption, SCF/BBL	1600	1400
Product nitrogen, ppm	< 0.2	< 0.2
Product aromatics, ppm	10	26

TABLE III

SUMMARY OF YIELDS AND REFINING COSTS FOR COAL-DERIVED OILS

F e e d		Yield of Desired Products, Liquid Volume Percent			(1) Total Investment, Millions of Dollars	(2) Refining Cost, \$/BBL of Desired Products
		motor gasoline	kerojet/ diesel	heating oil		
SRC - II	as received	21	66	-	1160	23.5
	as received	92	-	-	1030	20.5
	as received	25	-	63	870	17.5
Illinois H-Coal	as received	18	73	-	960	19.5
	re-distilled	20	72	-	850	17
	as received	96	-	-	950	18.5
	as received	20	-	75	660	13.5
Wyodak H-Coal	as received	28	65	-	750	14
	re-distilled	30	64	-	720	14
	as received	96	-	-	840	16
	as received	23	-	72	560	10.5
Lignite EDS	re-distilled	24	67	-	740	15
	as received	97	-	-	960	19.5
	re-distilled	88	-	-	820	15.5
	re-distilled	23	-	66	710	14.5

- (1) On-plot + off-plot + initial catalyst for capacity to produce 50,000 barrels per calendar day of desired products; first quarter, 1984. Excludes all costs for coal resources, mining, handling, liquefaction, and transportation.
- (2) Calculated rigorously by discounted cash flow analysis using 15% after-tax constant dollar rate of return, 6% background inflation rate, 100% equity financing, 48% income tax, 10% investment tax credit, depreciation according to 1982 Tax Equity and Fiscal Responsibility Act, 5-year tax life, 20-year project life.

FIGURE 1
DISTILLATIONS OF
ARABIAN CRUDE AND COAL-DERIVED OILS

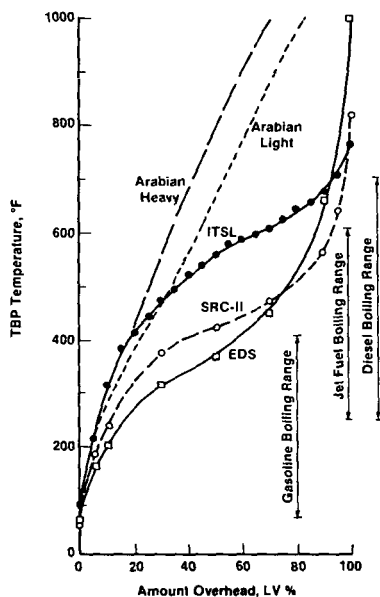


FIGURE 2
REFINING OF COAL SYNCRUDE TO
TRANSPORTATION FUELS

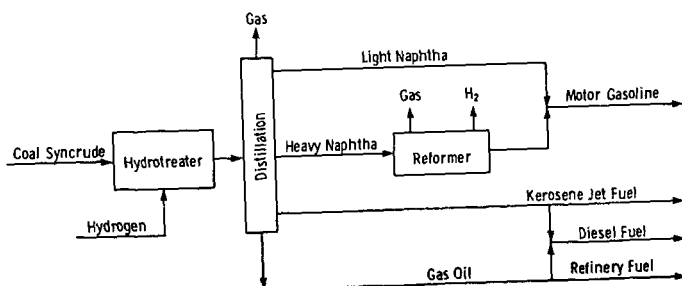


FIGURE 3
REFINING OF COAL
SYNCRUDE TO GASOLINE

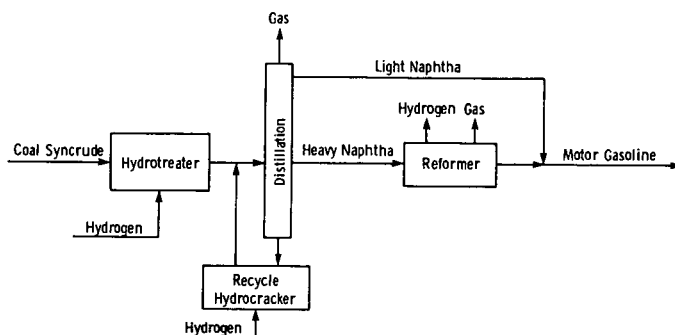


FIGURE 4
DOE CONTRACT DE-AC22-76ET10532
EFFECT OF FEED END POINT ON CATALYST
TEMPERATURE FOR HYDRODENITROGENATION OF
ITSL OILS WITH FRESH ICR 106 CATALYST

H₂ Partial Pressure = 2300 psia
Liquid Hourly Space Velocity = 0.5

